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Sustainable Silvicultural Systems: Lessons from Queensland, Australia.

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Abstract

The tropical rainforests of Queensland were included on the World Heritage List in 1988, after 100 years of commercial logging. This is testimony that the harvesting systems which were developed for these forests, left the forest in a reasonable condition. The paper reviews the silvicultural system, looks at its strengths and weaknesses, and summarizes several studies examining the sustainability of the timber harvest. Implications for timber production from tropical moist forests elsewhere in Asia are considered.

Introduction

Sustainable development means providing for the present generation (of all species, not just man) without compromising the needs of future generations. This balancing act impinges on both spatial and temporal distribution of all goods and services. Sustainable development means a fair and equitable distribution of resources for all species in all places during all times. It does not preclude timber harvesting or conversion of forests (tropical or otherwise) to other land uses. Our quality of life would be reduced greatly without agriculture and forest products! But it does behove us to plan land use changes and manage forests for the greatest good of the greatest number in the long run. The first imperative is prudence; we should consider all biodiversity as priceless while we learn to use and understand it.

Sustainable management of natural forests requires ecological harmony, economic viability and social acceptance. Here I emphasize the ecological aspects of timber harvesting, but social and economic aspects should not be overlooked, as in many cases, they may be the ultimate determinants of successful management (e.g. Vanclay 1993a).

Any harvest (timber, fibre, fruit or exudates) from any forest (tropical or temperate) should be gathered in a way which minimizes environmental impacts. Four basic principles are necessary, but not always sufficient, to achieve this. These are to minimize soil loss, minimize silting and pollution of streams, minimize destruction of trees in the residual stand, and to minimize disruption of ecosystem structure and function (e.g. Vanclay 1993b). We will examine these and other principles in the context of the Queensland rainforests.

The rainforests of north Queensland were included on the UNESCO World Heritage List in 1988 after 100 years of timber harvesting, an indication that timber harvesting did not foreclose future options. The management system devised for these forests was considered to be "the most complete example of sustainable management . . . found anywhere in the tropics" (Poore *et al.* 1989, p. 197). This paper summarizes forest management principles and guidelines used in Queensland, looks at their efficiency, and considers implications for others.

Timber harvesting in Queensland Rainforests: a brief history

Small pockets of rainforest occur along most of the coast and coastal ranges of Queensland, but the most timber production came from the tablelands west of the city of Cairns, between 16 and 19° south. Timber harvesting began in these forests in 1873, after red cedar (*Toona australis*) was found in the river valleys, and by 1900 cedar accounted for 72% of Queensland's export earnings. Unfortunately, there was little regulation of the harvest, and much timber was wasted (Adam 1992). It was 1885 before a royalty system was introduced (Frawley 1991). A Forestry Branch was formed within the Lands Department in 1900, and in 1906 a State Forests and National Parks Act was passed. In 1911, a professional forester, N.W. Jolly, was appointed, and his first annual report outlined two fundamental principles: the need to determine an annual cut based on the area and productivity of the forest rather than the demands of industry, and the importance of sufficient regeneration.

Rainforest alienation for agriculture virtually ceased by the mid-1960s, but frontier attitudes prevailed within the timber industry, which exerted considerable political influence to maintain low royalties and high quotas. This period saw the introduction of heavy earth moving machinery, and the associated problems of soil erosion and excessive canopy disturbance, and it was some years before the Department of Forestry asserted control and effective supervision. It was probably during the late 1960s and early 70s that environmental impacts of harvesting were greatest (e.g., Bruijnzeel 1992, Cassells 1992, Vanclay 1993c).

Global attention focused on the rainforests during 1970s, and in Australia there were protests against several proposed logging operations in native forests. The Australian Conservation Foundation (1981) adopted a policy that rainforest logging should cease, and proposed the creation of a "Greater Daintree

National Park". In 1988, the north Queensland rainforests were nominated for the UNESCO World Heritage List and commercial forestry operations were prohibited within the proposed area. Over 80% of the 'original' rainforest (i.e., existing when europeans arrived) still remains, but the proportion varies greatly by forest type (e.g., 47% lowland, 95% foothill, 86% upland; Winter *et al.* 1984).

The Queensland experience parallels developments in many other places, and may show what the future has in store for other tropical countries. By drawing on this experience, other countries may avoid some of the pitfalls and gain some helpful insights.

Rainforest Silviculture in North Queensland

The main thrust of rainforest management in Queensland has varied according to community attitudes and government policies. During its first 40 years, the Forest Service was preoccupied with rational land use planning and the creation of secure forest reserves. Jolly (Conservator 1911-18) emphasized the need to regulate the harvest and foster regeneration. Swain (1918-32) emphasized silviculture and good utilization. Many silvicultural experiments and permanent sample plots were established during the 1950s and 1960s, providing the foundations for growth and yield research (Anon. 1983). Experiment results suggested that silvicultural treatment (viz. killing the non-commercial trees) increased timber production on commercial trees, and in 1954 standard rules for logging and subsequent treatment were adopted. These were soon supplemented with a compulsory species list aimed at increasing the utilization of low-value species. Yields up to 2 m^3/ha/annum were obtained in selected experiments, but it is unlikely that these yields could be attained over extensive areas. Only 5000 ha had been treated by 1972 when silvicultural treatment stopped for economic and aesthetic reasons.

Effective management of these forests was consolidated during the 1980s (Whitmore 1990 p.123, Cassells 1992). Practical treemarking and logging guidelines were revised and implemented (Dale 1985, Ward and Kanowski 1985). New management guidelines drew on a range of research findings, and banned logging during the wet season, prohibited snigging through running streams, stipulated drainage for roads, tracks and loading ramps, and prohibited the use of earth or log-filled stream crossings. Forest operations during the 1980s demonstrated that commercial timber harvesting could be conducted with minimal impact if equipment operators adhered to a few simple guidelines (Crome *et al.* 1992). This requires training, incentives and supervision, of machine operators and of their employers.

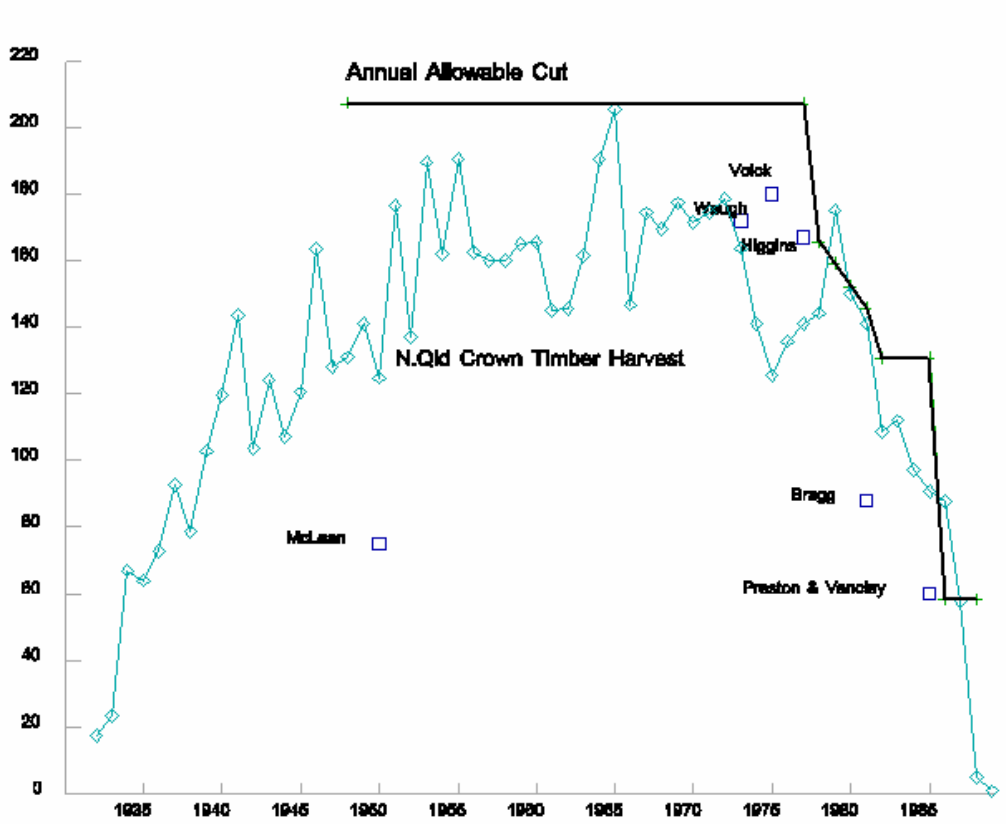

Figure 1. Sustained yield estimates, allowable cut and actual timber harvests from north Queensland Crown lands during 1932-89.

Timber Production

Figure 1 illustrates the sustained yield estimates, the annual allowable cut, and the actual timber harvest. The sustainable yield is a scientific estimate, quantitative and refutable, based on inventory data, growth estimates and clearly stated assumptions. The allowable cut should be based on this yield estimate, but may be adjusted for forest conversion and other objectives. If the productive capacity of the forest is not impaired (e.g., by soil erosion), the harvest may exceed the sustained yield for a short time, but these short-term gains must be offset by a reduced harvest in the future to allow the growing stock to recover. Ultimately, the allowable cut may be a political decision, but it is our responsibility as scientists and forest managers to discriminate clearly between an objective sustained yield estimate and a politically expedient allowable cut or quota.

The actual harvest from the forest may be subject to the vagaries of markets and prices, and may be much more capricious than yield estimates and quotas. To provide some flexibility for fluctuations in timber demand, it was policy in Queensland that the annual harvest could exceed the allowable cut in any year, provided that the five-year average did not exceed the allocation to any purchaser.

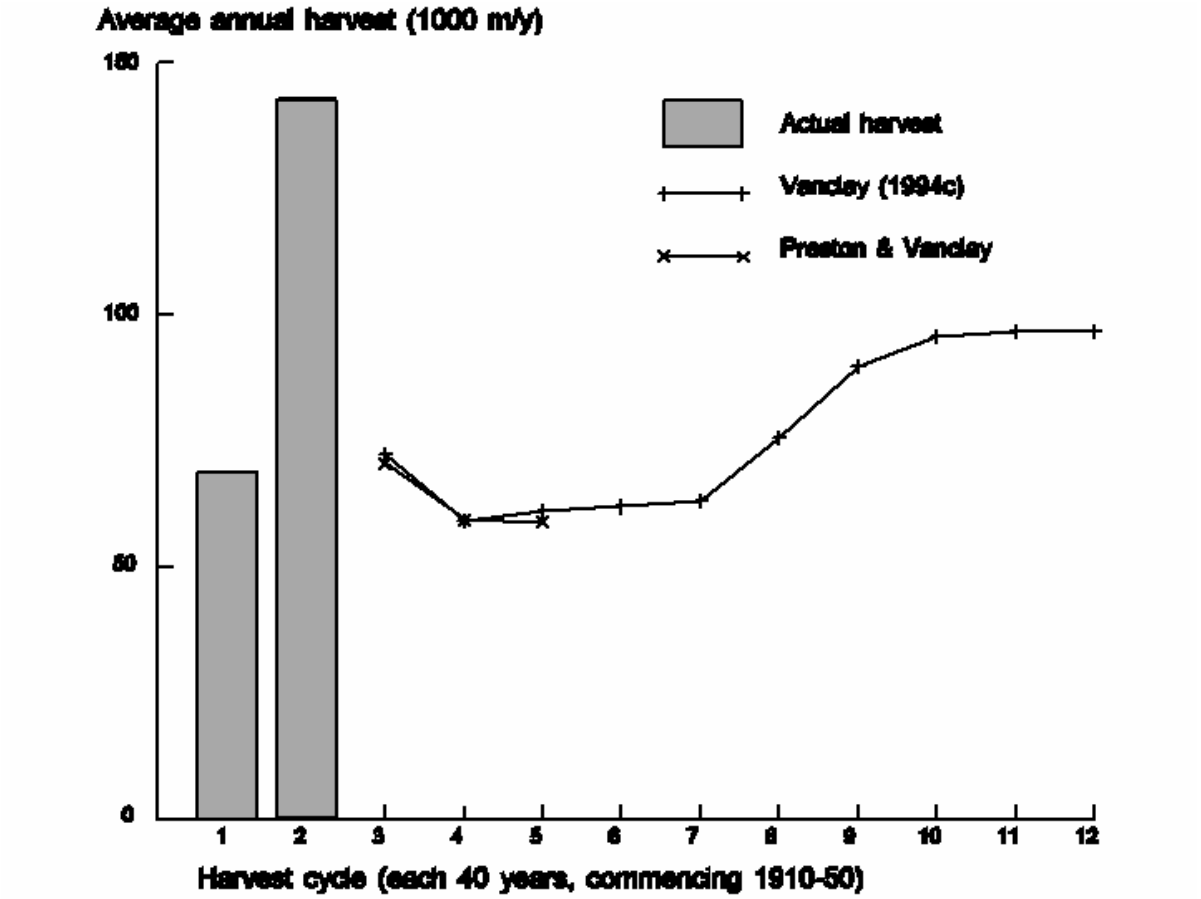

Figure 2. Historic 40-year harvesting trend (1947-86) and projected harvests for ten 40-year cycles.

During the early years of forestry in Queensland, the goal of forest management (having secured the forest estate) was to maximize timber production to support regional development; this objective is especially apparent in war-time and post-war annual reports. By the late 1940s, it became clear that timber harvests could not continue to escalate, and a quota was established. Initially the quota exceeded the estimated annual volume increment; the standing volume could sustain the large harvest desired for regional development. This optimistic quota could not be maintained, and by the late 1970s, a supply crisis was looming (Higgins 1977). The first serious attempts to quantify the sustained yield were made and the allowable cut was gradually reduced to sustainable levels. These three phases of yield regulation policy are evident in Figure 1.

Figure 2 summarizes simulation studies of potential future harvests, and contrasts these with the average harvest during the period 1947-86. These simulation studies suggest that past overcutting may depress potential future harvests for as long as 200 years, they recover to long-term sustainable levels.

Was it Sustainable?

It is difficult to assess the sustainability of a harvest at any point in time. Ultimately, sustainability can be proved only by

✓	Local community financially secure
✓	Secure permanent forest estate
✓	Minimal soil erosion
✓	Protect streams & steep slopes
✓	Timber species regenerate
☹	Representative national parks
✓	Stable harvesting prescription
✓	Non-declining even-flow harvest
☹	Management supported by research
✓	Economically viable
☹	Public & decision makers informed
☹	Community input in policy & planning

1. Appraisal of Queensland rainforest management in the 1980s.

demonstrating repeated commercial harvesting over a long period, coupled with detailed monitoring and inventory. An alternative is to examine the prognosis with simulation studies. Computer simulations of timber harvesting in part of this region suggested that a viable timber harvest could be sustained for more than 500 years (Vanclay and Preston 1989). Permanent plots that have been repeatedly harvested show no evidence of any decline in productivity. On the contrary, they provide evidence to support the assertion that any productivity decline can not exceed six percent per harvest (Vanclay 1990). But we still know rather little about many key processes of rainforest functioning (e.g., Webb and Kikkawa 1990, Goudberg and Bonell 1991), so any harvesting of timber and other products should proceed cautiously and conservatively.

More important than these theoretical simulation studies is the need to maintain the highest standards within practical constraints, to monitor and critically appraise operations, and to improve practices as new opportunities evolve. In this context, Queensland operations may be assessed as sometimes good, sometimes lacking, but showing a progressive improvement. By the mid-1980s, operations were reasonable, but a critical appraisal (Box 1) leaves some room for improvement.

The first requirement for sustainability is security. The local community must be secure; while people go hungry encroachment cannot be prevented. The forest estate should be secure, protected by the law and respected by the community. Stream buffers and steep slopes should be protected from harvesting. Forest operations should provoke little erosion, and should be succeeded by adequate regeneration of timber species. Invasion by weeds (exotic species, indigenous vines, palms or bamboos) may be the first symptom of a silviculture unsuited to the forest, and thus of unsustainable harvesting practices.

Adequate representative areas of all habitats should be protected in national parks or other conservation reserves. Although national parks protected 20% of Queensland's tropical

rainforest, they did not represent all habitats before the world heritage listing. By 1979 some 87% of rainforest formations were "reasonably well conserved" (Specht 1981, up from 50% in 1971), but the national parks system still fell well short of adequate representation for rainforest ecosystem (Working Group on Rainforest Conservation 1985). Most deficiencies occurred in the lowland rainforests threatened by agriculture, urban development and tourism, rather than by timber production. Specific deficiencies were noted by Webb (1966, 1987).

Harvesting prescriptions should be stable; continual erosion of the cutting limits is a sure sign of overcutting. Some revisions to enhance practices or improve economics may be acceptable, provided that changes are supported by research. Practical and economic issues may preclude a non-declining even-flow on an annual basis, but the several-year running average harvest should be stable, smooth and close to the estimated sustainable yield.

Management should be supported by research and monitoring. Research should address a range of issues, ranging from taxonomy and forest dynamics to silviculture and applied harvesting research. Queensland had a promising research program during the 1970s, but this was curtailed in the 1980s and many questions remained unresolved (Goudberg and Bonell 1991). However, many studies of the effects of logging in these forests have been published, and collectively provide a unique demonstration of one possible approach to sustainable timber harvesting. These studies have investigated the effects on fauna (e.g. Crome and Moore 1989), flora (e.g. Crome et al. 1991, Nicholson et al. 1988, 1990), hydrology (e.g. Gilmour 1971), soils (e.g. Gillman et al. 1985, Congdon and Herbohn 1993) and litter dynamics (e.g. Herbohn and Congdon 1993), and indicate that timber harvesting in accordance with the guidelines is probably benign and that any environmental effects are transient and localized.

Timber harvesting should be economically viable. Financial data relating to the Queensland rainforests were rarely made publicly available, but Higgins (1977) stated that during 1975-76 expenditure on rainforest management was AUD$730,000 and that revenue was $1,271,000. For many years, royalties were kept artificially low, but Harris (1987) estimated that value-adding by the timber industry amounted to $25 million per annum.

The forest is a communal asset, and the community should have a say in policy, planning and management. For such input to be meaningful, the public must first understand the possibilities and objectives of management. This demands considerable effort from forest managers in education and community liaison. Ultimately, many decisions influencing the fate of the forests are political, and foresters must inform politicians and other decision makers about possibilities and consequences. It is noteworthy that sustainability begins and ends with the local and wider community (see Box 1).

1. A formal logging plan should be pepared before operations commence.
2. Logging should be excluded from buffer strips, steep slopes (20°, 25° and 30° respectively for low, moderate and high erosion hazard), and areas designated for protection or conservation.
3. Buffer strips are required for watercourses with a catchment area over 60 ha (100 ha if low erosion hazard), and should be 30 m wide for permanent watercourses and 20 m otherwise (10 and 20 m respectively if catchment gradient does not exceed 15°).
4. Roads should be located to minimize earth works (e.g. on ridge tops and moderate slopes), and should not exceed 7.5 m and 5.0 m in width for major and minor extraction roads respectively. Side cuts should be minimized (avoided on slopes over 30°; 25° if high erosion hazard). Spill should be stabilized with a cover crop. Grades should not exceed 8°.
5. Trees must be felled in a safe and proficient manner, using directional felling and low stump heights (less than 60 cm).
6. The extraction system must be planned to minimize tracks and avoid damage to residual trees. Snig tracks should not exceed 25° (15° and 20° in high and moderate erosion hazard areas) and should not be more than 4 m wide. Logs should be extracted uphill, away from watercourses. Machines must have at least 30 m winch cable, must not exceed 100 kw in power, and must have a blade not more than 4 m wide. Where possible, the front of the log must be raised during snigging.
7. Log loading ramps must be located on ridges or on slopes not over 6°, and must not be within 10 m of a buffer, drainage line or protection area. There should not be more than one ramp for every 5 ha logged (10 ha in steep terrain over 15°). Ramps should not exceed 500 m² (750 m² permissable if only one per 10 ha).
8. All vehicles must comply with regulations regarding configuration and maximum loads. Loads must be securely tied with at least two chains.
9. Drains must be constructed to divert water from exposed soil on tracks and ramps, at the end of operations or at the end of every working week if work is not "to a face". Drains are required for every 4 m vertical distance (2 m if moderate or high erosion hazard) and should be 50 cm high/deep.
10. Logs are not to be snigged through water. Culverts or bridges are required for permanent stream crossings. Temporary crossings must be removed on completion of operations.
11. There should be no felling or extraction during the wet season (1 January–31 March). All snigging operations must stop when the soil is saturated or there is free surface water flow.

2. Extract from Queensland logging guidelines (Just 1991).

The Queensland Guidelines

Sustainable silviculture relies on the minimum disturbance to ecosystem structure and function that will provide an economic harvest and favour regeneration of the harvested species. This requires, amongst other things, that soil and canopy disturbance are minimized. Soil erosion can be reduced relatively easily, by not logging steep slopes, by locating and constructing extraction tracks with easy grades and adequate drainage, by minimizing soil disturbance, and by ceasing operations during periods of heavy rain. Tracks of exposed mineral soil should not be made to each log. Rather, the organic material of the soil surface (and any understorey plants) should be disturbed as little as possible. Winches, grapples and logging arches to lift the leading end of the log clear of the ground may help to minimize soil disturbance during extraction. Whilst these provisions are easy to define in principle, they are more complex to implement in practice. Blanket rules fail to take into account differences in soils and equipment, and a worse-case provision may be impractical. In Queensland, an erosion hazard rating based on soil structure and parent material (sandy soils from sandstones and granites = high; loamy soils from shales and metamorphics = moderate; and red clays from basalts = low erosion hazard) provided the basis for many guidelines (Box 2). In the seasonal tropics, a wet season cessation of logging operations may be beneficial, but only if drains and culverts are maintained before and during the wet season. Soil erosion occurs not only during logging operations, but also following the cessation of logging. To minimize this erosion, it is essential to check drains and culverts on completion of logging, and to install cross-drains to intercept water running down roads and tracks. Silting of streams will also be reduced by these provisions, and can be further reduced by maintaining buffer strips along streams, and by using bridges and culverts (designed to cope with expected peak flow) rather than fords. Trees should not be felled into streams, and any obstruction to stream flow caused by logging should be cleared on completion of logging.

Productivity may be lost, not only through the physical loss of soil by erosion, but also through changes in soil structure caused by compaction, impeded drainage and destruction of the soil profile (e.g. bringing subsoil and rocks to the surface). Obviously, soil disturbance should be minimized, but it is not always clear if tracked or rubber-tyred machinery is preferable. Smaller specialist machines are preferable to general purpose heavy earth-moving machinery, and it is important that the blade be no bigger than necessary. However, in practice, it is usually not the machine but the operator who determines the extent and nature of disturbance, and training and incentives may do much to reduce impacts. Blanket rules are not sufficient. Rather, it is necessary for operators to understand the principles and intent of the guidelines, and to have the motivation to do a good job. This implies effective supervision, penalties for non-compliance, and performance clauses for contractors and purchasers. The harvesting guidelines used in north Queensland (Box 2) were based on these principles, were effective in these seasonally wet forests, and

1. Tree harvesting should be consistent with the objective of sustained yield, and should leave sufficient commercial trees to provide for future harvests.
2. Impacts should be minimized by following these and other guidelines. Canopy disturbance must be minimized, and at least 50% canopy must remain on completion of the operation. Adequate seed sources must remain after logging.
3. To provide for future harvests, desirable tree species must be retained and the felling direction of harvested trees must be chosen to minimize damage to the growing stock. Seed trees and other trees to be retained must be clearly marked if they appear vulnerable to logging damage.
4. All trees to be harvested will be marked by a forest officer, who will mark the tree with a unique number and the direction for felling. All trees exceeding the cutting diameter (100, 80, 70, 60 or 50 depending on species, see Preston and Vanclay 1988) are marked for felling unless required as a seed tree or an outstanding tree.
5. Seed trees are required at an average spacing of 40×40 m, and should be at least 40 cm diameter, but if possible, less than the retention limit (usually cutting limit plus 20 cm, Preston and Vanclay 1988). Seed trees should have long boles (over 6 m) with healthy, well-developed crowns. Preference should be given to conserving the more desirable species as seed trees. Seed trees are not required if there are more than 75 well-spaced trees of group A species over 3 m high, or more tha 175 well-spaced trees of any commercial species over 3 m high.
6. Trees of outstanding vigour and form should be retained for future harvest, even if over the cutting limit, and up to 7 of these trees may be retained per hectare.
7. Trees over 40 cm diameter but below the cutting limit may be harvested only if they are defective or severely damaged.
8. Rare species (e.g. *Agathis microstachya, Macadamia* "satin silky oak") are to be protected from logging.

3. Extract from Queensland treemarking guidelines (Anon 1986).

provided the basis for the ITTO Guidelines of Best Practice (ITTO 1990a).

Tree felling and extraction also requires the skill and the will of operators to minimize destruction of trees in the residual stand. In Queensland, trained Forest Service staff marked and sequentially numbered all trees to be removed, and indicated the direction in which these trees were to be felled. The direction of felling was chosen so as to concentrate the crowns of felled trees into groups, and to avoid damaging trees required for the residual stand. The system of numbering trees and logs helps ensure that no merchantable logs are overlooked, and the

sequential numbering makes it easier to find these logs. The CELOS system (Jonkers and Schmidt 1984) also required the preparation of maps showing the location of logs, to assist relocation and to minimize unnecessary travel by the skidder. In Malaysia, climber cutting a year or more prior to felling has also been shown to reduce damage to trees required for the residual stand. Care in extracting logs is necessary to avoid damaging the bark of trees in the residual stand, as such damage assists entry of disease and decay. Extracting short log lengths rather than tree-length sections helps reduce soil disturbance and damage to the residual stand. It is false to assume that shoddy logging operations are more profitable. On the contrary, good logging practices may reduce costs, increase productivity, and reduced damage to the residual stand may yield a 30% increase in value of the next harvest (ITTO 1990b).

It is more difficult to minimize disruption to ecosystem structure and function. It is inevitable that any logging will alter the stand structure and likely that the relative species composition may be affected transiently if not permanently. The art of silviculture is to minimize the impact of such changes, and to promote the rapid development of a new stand with desirable characteristics similar to the original stand. Many "weeds" (i.e. exotic and indigenous plants capable of multiplying rapidly and dominating a site where previously absent or present only in small numbers; unrelated to economic importance) including bamboo, some palms and many vines, are light demanding, and too much disturbance may favour invasion and infestation by such weeds. These may form a stable sub-climax and impede regeneration of tree species for many decades. Thus in many cases, minimal disturbance is the safest approach.

Queensland foresters were fortunate to have valuable tree species which were relatively light demanding and regenerated readily, and to have few problems with bamboo, vines and other weeds. Even in these forests, the minimal disturbance approach seemed to be the most reliable, and logging guidelines stipulated that not more than 50% of the canopy was to be removed in harvesting. In practice, canopy disturbance was often much less than this permitted maximum (e.g. Crome *et al.* 1992). The timber harvesting guidelines formulated for Queensland rainforests provided for (Vanclay 1990):

a) logging guidelines sympathetic to the silvicultural characteristics of the forest, providing for adequate regeneration of commercial tree species and discouraging invasion by weeds (principally climbing vines);
b) treemarking by trained staff who specified trees to be retained, trees to be removed and the direction of felling so as to retain vigorous advance growth, to harvest mature and defective trees, and to minimize destruction of the residual stand (Box 3);
c) incentives for logging contractors to be trained and for appropriate logging equipment to be used, so as to minimize soil compaction, disturbance and erosion;
d) prescriptions to protect adequate stream buffers and steep slopes from logging;
e) sufficient areas for scientific reference, feature protection and recreation to be identified and excluded

from logging;

f) and for deficiencies in an evolving system to be recognized and remedied, leading to an improved system.

This silvicultural system is one approach which may be successful, but other alternatives also exist. The Malaysian Uniform System involved complete removal of the overstorey canopy in lowland dipterocarp forests, and where adequate regeneration existed, it provided good recovery and canopy closure by the commercial dipterocarp species (Wyatt-Smith 1963). Secondary forest may also regenerate satisfactorily after shifting cultivation, and this suggests another possibility. The success of regeneration following such cultivation seems to depend upon the same two factors: preventing soil loss and overcoming weed problems. Thus successful forest management will depend more on an understanding of stand and weed dynamics than on blanket prescriptions.

Lessons for Others

Perhaps the most important lesson from Queensland, is that community attitudes change, sometimes quickly. There is a growing appreciation that rainforests are a valuable asset to be used wisely. Waste and destruction will hasten this change in attitude and will strengthen the demands for complete preservation (e.g., Watson 1990, Adam 1992). However, the Queensland experience shows that rainforests can be managed wisely, profitably and sustainably, if a few simple guidelines are followed.

In Queensland, many commercial species were 'small gap' species, so an appropriate silviculture was a single tree selection system with minimal disturbance. Such a system is desirable for many other reasons, including soil and biodiversity conservation, but should only be used where it is compatible with specific species requirements. In forests dominated by pioneer species (e.g., *Tectona*, *Swietenia*), other systems may be preferable.

Success or failure of such a system lies in harvesting, including the felling, extraction and hauling of timber. The harvest must be planned and supervised to minimize damage, to minimize the number and length of roads and tracks, and ensure their optimal placement. Felling direction should be controlled to avoid damage to residual trees, and this demands skilled operators. Soil disturbance should be minimized in all operations, especially during extraction of logs from the stump to the loading site; this requires appropriate equipment and skilled operators. Roads should be designed and placed to avoid steep grades and streams. Drainage is all-important, both during and on completion of operations. Success depends both on what you log, and what you do not log. Do not log stream buffers, steep slopes, conservation areas, connecting corridors or during the wet season.

Finally, harvesting, like all aspects of forestry, is about people as much about trees. Success requires training,

incentives and supervision. It also means public relations. Explain to people what you are doing, why and how you are doing it. Listen to what they say, to their hopes and aspirations. And learn to discuss in an amicable way, and to compromise, before small issues become big problems. Your forest depends on it!

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